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STUDY OF HEAT TRANSFER CHARACTERISTICS OF HOT-GAS IGNITERS

Third Quarterly Progress Report for Period Ending
15 March 1967

J. A. Wrubel

Rocketdyne, A Division of North American Aviation, Inc.,
6633 Canoga Avenue, Canoga Park, California

TECHNICAL REPORT AFRPL-TR-67-83

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Air Force Rocket Propulsion Laboratory
Research and Technology Division
Edwards, California
Air Force Systems Command
United States Air Force

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FOREWORD

This technical report presents the effort conducted during the third quarter under a contract entitled "Study of Heat Transfer Characteristics of Hot-Gas Igniters." The study was conducted by the Research Division of Rocketdyne, a Division of North American Aviation, Inc. The third quarter effort, conducted during the period 16 December to 15 March 1967, was authorized by the USAF Rocket Propulsion Laboratory under Contract AF04(611)-11613. The Air Force Project Monitor is 1/Lt. C. E. Payne, RPMC.

This report has been assigned the Rocketdyne Report No. R-6856-3.

Publication of this report does not constitute Air Force approval of the report's findings or conclusions. It is published only for the exchange and stimulation of ideas.

CHARLES COOKE
Division Chief,
Solid Rocket Division

ABSTRACT

This program is concerned with determining the convective heat transfer characteristics of pyrogen igniters in both the aft-end and head-end configurations for three-pointed star and conocyl motor grains. Heat transfer modeling tests utilizing thin-plate calorimetric techniques are being conducted to evaluate the heat transfer distribution. The third quarter effort reported herein was directed toward completion of the model heat transfer tests, preparation of the model heat transfer data for machine computation, initiation of demonstration motor build-up, continuance of the head-end and aft-end fluid dynamic analysis, completion of a description of the "HOTGAS" computer program, and initiation of that portion of data reduction requiring machine computation.

CONTENTS

SUMMARY

During the third quarter of the "Study of the Heat Transfer Characteristics of Hot-Gas Igniters," major effort was directed toward completion of model heat transfer tests, test data analysis, demonstration motor build-up, and head-end and aft-end fluid dynamic analysis. The planned total of 90 model heat transfer tests were completed and the test data organized and tabulated. A description of the "HOTGAS" computer program was prepared to facilitate the assembly of the model heat transfer data for machine computations. These required computer runs were initiated toward the end of the period. Demonstration motor build-up is near completion. Fabrication of test section components is approximately 90 percent complete while test stand build-up is 50 percent complete. A literature survey in support of the head-end and aft-end fluid dynamic analysis was concluded. Review and analysis of the gathered material is continuing.

Demonstration motor build-up will be completed at the beginning of the fourth quarter. Shortly thereafter motor testing will commence. Data analysis and correlation will be completed toward the middle of the next quarter and the fluid dynamic analysis will be completed near the end of the next quarter. The demonstration motor firings will be conducted according to the testing schedule established during the first quarter.

INTRODUCTION

A 12-month program entitled "Study of Heat Transfer Characteristics of Hot-Gas Igniters," was initiated by the Rocketdyne Research Division under Contract AF04(611)-11613 on 16 June 1966. The objective of this study is to develop relationships which predict convective heat transfer from a hot-gas igniter to a solid propellant grain and to demonstrate that such relationships permit a quantitative prediction of the ignition delay. These relationships, based on a comprehensive testing program, will be derived for typical head-end and aft-end, hot-gas igniters for practical solid propellant grain designs, i.e., stars and conocyls. The testing program consists of: (1) a critical test to investigate a transient boundary layer mechanism, (2) schlieren tests to gain a fundamental understanding of the interaction of fluid dynamics upon the heat transfer from hot-gas igniters, (3) model heat transfer tests to determine the influence of geometric changes of solid propellant grain ports and position of the igniter nozzle on the heat transfer to the propellant surface, and (4) demonstration motor firings to determine the applicability of the developed relations to an actual propellant system.

Frequently, solid propellant rocket motors are ignited by hot-gas sources such as smaller burning solid propellant charges (pyrogen igniters) or pyrotechnic grains which exhaust their combustion products into the main combustion chamber through convergent or convergent-divergent nozzles located in either the head-end or aft-end of the motor. Historically, the design of hot-gas igniters evolved from empirical approximations developed by motor manufacturers based upon massive testing programs involving many different motor systems. Current refinements of available approximations still result in more costly hot-gas igniter design than would be necessary if generalized design principles were available. Because the pre-ignition period in hot-gas ignition largely involves a convective heat transfer process, a program under Contract AF04(611)-9884, entitled "A Study of the Heat Transfer Characteristics of Hot-Gas Ignition," (Ref. 1)

was conducted. This program developed generalized correlations and analytical procedures on a substantial theoretical and experimental basis that could define particular simple hot-gas ignition system requirements. The use of modeling techniques facilitated the gathering of pertinent information in a rapid and inexpensive manner.

Current ignition research programs are progressing significantly toward the elevation of ignition system design from an art to a science. Relationships correlating heat flux, pressure, and ignition delay have been developed for some rubber-base propellants under Contract AF04(611)-9701, entitled "Ignition of Solid Propellant Motors Under Vacuum," (Ref. 2). Of fundamental importance in the practical utilization of the preceding information is knowledge of the characteristics and mechanisms of the heat delivery from the igniter gas to the propellant surface. This was developed for cylindrical geometry in Ref. 1. The extension of the previously developed modeling techniques and procedures to more complex geometries (i.e., star and conocyl configurations), coupled with the data for a particular propellant from Ref. 2 , should allow, for the first time, the scientific tailoring of an igniter to a specific solid propellant motor without recourse to empirical rules.

During the first quarter effort on the "Study of Heat Transfer Characteristics of Hot-Gas Igniters," (Ref. 3), major effort was directed toward reactivation of the hot-gas heater, design of test section components, procurement of materials, hardware fabrication, the computer program changeover, and test planning. Reactivation of the hot-gas heater eliminated the problem of oxide deposition on test section hardware, allowed far more rapid changeover of test section thermocouple instrumentation, and increased the response rate of the gaseous nitrogen pressure regulator. Test stand modifications were completed, and the checkout of the apparatus and design approaches was successful. All test section designs were completed. Fabrication was completed for: components for the critical experiment, components for the schlieren test, the optimum expansion ratio model igniter nozzles, and components for long-lead-time items for the demonstration motor firings. A tentative test matrix that included a total of 115 tests was formulated.

During the second quarter (Ref. 4), major effort was directed toward fabrication of the test sections for the model heat transfer experiments, procurement of the propellant grains for the demonstration motor test series, the conducting of a majority of the tests for the experimental phase of the program, completion of the computer program changeover, and test data analysis.

The model heat transfer test sections consist of star port and conocyl port grain configurations incorporating a rational change of geometric variables, i.e., star point angle, cone angle, cone spacing, and cross-sectional area. Eight test sections (five star and three conocyl) were fabricated.

A subcontract was let to the United Technology Center for the loading of UTP 3001 solid propellant into Rocketdyne-supplied hardware. The eight demonstration motor cartridges ordered consisted of three cylindrical port, four star port, and one solid port grain configurations.

The high gas temperature critical experiment and schlieren test series were concluded. The model heat transfer experiments were approximately two-thirds completed with 57 of a planned 90 tests accomplished. The computer program changeover was completed with the successful run of a trial case.

Test data analysis was completed for the high gas temperature critical experiment and schlieren tests. The critical experiment demonstrated that the heat transfer coefficient remained constant as a function of time when a high driving temperature potential was present. A letter was sent to those named on the final report distribution list of Contract AF04(611)-9884, alerting them to this significant result. A general qualitative analysis of the schlieren tests which establishes the flow field created by head-end and aft-end, hot-gas igniters is presented in Ref. 4.

During the third quarter effort, described in detail in this report, the following tasks were accomplished: completion of the model heat transfer tests, preparation of the model heat transfer data for machine computation, initiation of build-up for the demonstration motor firings, continuance of the head-end and aft-end fluid dynamic analysis, completion of a description of the "HOTGAS" computer program; and initiation of that portion of data reduction requiring machine computation.

EXPERIMENTAL EQUIPMENT

A complete description of the hot gaseous nitrogen supply system and associated subsystems, located in Pit 2 of the Combustion and Heat Transfer Laboratory, Santa Susana Field Laboratory, is contained in AFRPL 65-158, the final report under Contract AF04(611)-9884. This test facility and applicable test section hardware fabricated previously are being utilized in the current program and, because their description has been presented previously, only modifications to the existing apparatus and newly designed equipment will be reported.

The design drawings of the demonstration motor case, head closure, window retainer, and exhaust nozzles were prepared early in the quarter. All other components necessary for a demonstration motor assembly were taken from an existing Rocketdyne solid propellant evaluation motor. The windowed demonstration motor case allows the use of a 12-inch-long propellant grain with an outside diameter of 6 inches. The 8.25 by 1.75 inch centered window section will enable observation of the ignition location for all of the various test conditions. Pressure instrumentation (high-response Photocon and medium-response Wiancko transducers) and the pyrogen igniter will be mounted in the forward closure of the demonstration motor. When testing in the aft-end mode, a plug will be inserted in the head-end pyrogen igniter port. To fulfill the required test configurations for this series, four ATJ graphite nozzle throat inserts were designed. Dimensions were established to be consistent with configurations that were tested during model heat transfer experiments except that the divergence half-angle for the nominal 4-inch-diameter nozzles was changed from 15 to 7 degrees.

Fabrication of the demonstration motor inert parts is near completion. The head closure was constructed and the ATJ graphite throat inserts were received from a vendor. Machining of the window retainer and demonstration motor case is 90 percent complete. Holes must still be drilled and tapped in these two parts. It is anticipated that fabrication will be completed early during the next quarter.

The UTP 3001 solid propellant grains were received from the United Technology Center. Longitudinal slots were cut through the grain web to allow photographic observation of ignition in the motor grain port. Plexiglas spacers were bonded into the slots and inert propellant was applied to sharp edges to inhibit spurious ignition at these locations. This completed propellant grain build-up.

Test stand build-up is approximately 50 percent complete. The electrical and instrumentation system which includes two Photocon lines, two Wiancko lines, igniter fire circuit, hydraulic cylinder actuation circuit, motion picture camera power lines, and timer circuit has been installed. Also, the actuator system has been assembled. Early next quarter, the actuator system and demonstration motor assembly will be installed in the auxiliary pad at the Combustion and Heat Transfer Laboratory. This will complete the effort on fabrication and build-up of experimental equipment for this contract.

EXPERIMENTAL OPERATIONS

During the third quarter, model heat transfer testing was completed. The planned total of 90 tests utilizing star port and conocyl port test sections in both the aft-end and head-end igniter configuration was accomplished. The test series included 55 head-end tests (35 star port and 20 conocyl port) and 35 aft-end tests (22 star port and 13 conocyl port). Test configurations were as shown in Ref. 3 , but the firing order was changed to reduce the number of physical changes between tests. The final test series, demonstration motor firings, will be accomplished during the fourth quarter.

DATA ANALYSIS

During the third quarter, a description of the "HOTGAS" computer program was written, test data reduction of the model heat transfer experiments continued, and preliminary analysis enabling the prediction of the ignition location and ignition delay for the demonstration motor firings was accomplished.

A general discussion of the computational process used in heat transfer data reduction was presented in Ref. 4 . For continuity, some of that material is repeated in the following description of the "HOTGAS" computer program.

"HOTGAS" COMPUTER PROGRAM

Input

The input data for the HOTGAS computer program are received from two sources. The primary data are the Beckman 210 transient test data. The raw test data are scaled into temperature units (F) by Rocketdyne's 2T825 scaling program. This scaling program is run simultaneously with the HOTGAS reduction program and it feeds the data directly via the TRANS subroutine. The secondary input consists of constant values, option controls, and title heads. This is read in via input data cards. The input list and format is shown in Table 1.

Output

The printed output consists of time, gas-side and outside wall temperatures, heat fluxes, and gas temperatures.

A Stromberg-Carlson 4020 cathode ray tube (CRT) plots the calculated data on 9 inch by 9 inch graphs. Five types of graphs are available: (1) gas-side and outside wall temperatures vs time, (2) heat flux vs time,

TABLE 1

FORTRAN FIXED 10 DIGIT DECIMAL DATA

DECK NO. DATA PROGRAMMER ______ DATE / / PAGE 1 of ____ JOB NO. ______

	NUMBER	IDENTIFICATION	DESCRIPTION DO NOT KEY PUNCH
1	998		SIGNAL TO START CASE
13			
25			
37			
49		73 80	
61		1	
1			TITLE HEAD — LABELS CRT'S
13			(BOTTOM LINE)
25			
37	STAND		
49	- D	73 80	← STAND NUMBER
61	ATE / /	2.	← RUN DATE
1			TITLE HEAD
13			(SECOND LINE)
25			
37			
49		73 80	
61		3.	
1			TITLE HEAD
13			(FIRST LINE)
25			
37			
49		73 80	
61		4.	

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TABLE 1

(Continued)

DECK NO. DATA PROGRAMMER ________ DATE / / PAGE 2 of ____ JOB NO. ________

Col.	NUMBER	VECTOR LOCATION	IDENTIFICATION	DESCRIPTION DO NOT KEY PUNCH
1		001		C_1 } $k = C_1 + C_2\left(\frac{T_{w1}+T_{w2}}{2}\right)$ THERMAL CONDUCTIVITY OF WALL MATERIAL (BTU/IN-SEC-°F)
13		002		C_2
25		003		B_1 } $C_{p_{gas}} = B_1 + B_2 T_{corr} + B_3 T_{corr}^2 + B_4 T_{corr}^3$ (BTU/lbm-°F)
37		004		B_2
49		005		B_3
61		006	5	B_4
1		007		AREA { IF (−), WILL READ INDIVIDUAL AREAS FROM A(251) TO A(300); IF (+), WILL ACCEPT VALUE AS CONSTANT AREA [in²]
13		008		D - DIAMETER OF TEST SECTION (in.)
25		009		WD - $\dot{m}$ = WEIGHT FLOW RATE (lbm/sec)
37		010		WØA ≈ $\rho\zeta$ (lbm/in²) USED IN $q/A = \rho\zeta\, C_p \frac{dT}{dt}$
49		011		NUMBER OF DATA POINTS TO AVERAGE
61		012	6	HTLØSS IF (−) NO HEAT LOSS CORRECTION OF T_{gas}; IF (+) HEAT LOSS CONSIDERED
1		013		ζ - TEST SECTION WALL THICKNESS (in.)
13		014		D_1 } $C_p = D_1 + D_2\left(\frac{T_{w1}+T_{w2}}{2}\right)$ SPECIFIC HEAT OF WALL MATERIAL (BTU/lbm-°F)
25		015		D_2
37		016		GAS TEMP { IF (−) WILL CHECK A(201) FOR TC IDENTIFICATION; IF (+) WILL ACCEPT VALUE AS CONSTANT TEMP (°F)
49		017		NRUN - RUN NUMBER
61		018	7	OPTAPE IF (−) NO MAGNETIC TAPE OUTPUT; IF (+) WILL STORE h, TIME, & X/D ON TAPE
1		019		NCHAN - NUMBER OF CHANNELS REQUESTED IN PRIMARY LIST
13	1.0	020		N - READS EVERY Nth TEMP, USE 1.0
25		021		M - SAMPLE REDUCTION FACTOR IF > 1.0, WILL CAUSE SKIPPING OF DATA
37		022		X/D LIMIT ON H vs. X/D PLOT, ROUND OFF (X/D)MAX
49		023		H LIMIT ON H vs X/D PLOT
61		024	8	

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TABLE 1

(Continued)

DECK NO. DATA PROGRAMMER ______ DATE / / PAGE 3 of ____ JOB NO. ______

	NUMBER	VECTOR LOCATION	IDENTIFICATION	DESCRIPTION DO NOT KEY PUNCH
1	6.0	025		SECTION TO USE
13		026		SLICE TO USE
25		027		LOGICAL TAPE UNIT OF DATA TAPE
37		028		
49		029		
61		030	90	
1		031		
13		032		CRTØPT {IF(-) NO PLOTS AT ALL. IF(+) WILL CHECK FOLLOWING OPTIONS
25		033		T_1 & T_2 vs. Time PLOT } IF(+), PLOT
37		034		Q/A vs Time PLOT } IF(-) OR BLANK, NO PLOT
49		035		H vs. Time PLOT
61		036	100	H vs. X/D PLOT
1		151		PRIMARY LIST OF PARAMETERS THAT WILL BE
13		152		FULLY EVALUATED. GIVE THE
25		153		POSITION NUMBER ACCORDING
37		154		TO THE ORDER OF SCALING.
49		155		THIS LIST CONTINUES TO LOCATION
61		156	120	A(200) AND ADDITION CARDS PERMITTED.
1		201		GAS TEMP TC IF A(16) IS NEG. GIVE POSITION NUMBER OF CHANNEL PER SCALING ORDER.
13		202		SECONDARY LIST OF PARAMETERS TO BE EVALUATED
25		203		TO TEMPS ONLY. LIST PER POSITION
37		204		NUMBER. THIS LIST CONTINUES TO
49		205		LOCATION A(240), ADDITIONAL CARDS
61		206	140	PERMITTED.

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TABLE 1

(Continued)

DECK NO. DATA PROGRAMMER ______ DATE / / PAGE 5 of ____ JOB NO. ______

	NUMBER	IDENTIFICATION	DESCRIPTION DO NOT KEY PUNCH
1	999		END OF CASE
13			
25			
37			
49		73 80	
61		240	
1	/*		END OF JOB
13			
25			
37			
49		73 80	
61		99900000	
1			
13			
25			
37			
49		73 80	
61			
1			
13			
25			
37			
49		73 80	
61			

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TABLE 1

(Concluded)

DECK NO. DATA PROGRAMMER ______ DATE / / PAGE 4 of ______ JOB NO. ______

	NUMBER	VECTOR LOCATION	IDENTIFICATION	DESCRIPTION DO NOT KEY PUNCH
1		251		AREAS - IF A(7) IS NEG., LIST INDIVIDUAL AREAS
13		252		($in.^2$) HERE, IN SAME ORDER AS PRIMARY
25		253		LIST. THIS LIST CONTINUES TO A(300),
37		254		ADDITIONAL CARDS PERMITTED. IF A(7)
49		255	73 80	IS POS. (+) OR HEAT LOSS NOT CONSIDERED,
61		256	160	LEAVE THIS LIST BLANK.
1		301		X LOCATIONS OF TC'S FOR H vs X/D PLOT. THIS
13		302		(in) LIST CONTINUES TO A(350), ADDITIONAL
25		303		CARDS PERMITTED. BE SURE THAT THE
37		304		ORDER OF THIS LIST CORRESPONDS
49		305	73 80	TO THE ORDER OF THE PRIMARY LIST.
61		306	180	IF NO H vs X/D PLOT, LEAVE THIS BLANK.
1		351		I.D. LIST FOR PRIMARY PARAMETERS. ANY
13		352		IDENTIFICATION NUMBER FOR LABELING
25		353		PARAMETERS. MAINTAIN CORRESPONDING
37		354		ORDER TO PRIMARY LIST. THIS LIST
49		355	73 80	CONTINUES TO A(400), ADDITIONAL
61		356	200	CARDS PERMITTED.
1		401		I.D. FOR GAS TEMP T.C.
13		402		I.D. LIST FOR SECONDARY PARAMETERS.
25		403		MAINTAIN CORRESPONDING ORDER TO
37		404		SECONDARY LIST. THIS LIST CONTINUES
49		405	73 80	TO A(440), ADDITIONAL CARDS PERMITTED
61		406	220	

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(3) heat transfer coefficient vs time, (4) heat transfer coefficient vs x/D position with time being the changing parameter, and (5) gas temperature vs time. These five graphs are controlled by option variables that are read-in on data cards. If the corresponding option value is positive (+), plot; if negative (-), no plot. There is also an option to store the calculated heat transfer coefficients with the corresponding times and x/D positions on magnetic tape. The data are labeled by a run number and a title head that is read-in on the data cards.

Computations

The HOTGAS computer program is a revision of another heat transfer data reduction computer program (7T109). The revisions consist principally of conversion from Fortran IV to Fortran H and expansion of the program for versatility. The basic calculating methods remain unchanged.

The time base used in the program is calculated. The initial time is obtained from the Beckman scaled data tape, and the Δt is calculated from

$$t = t_i + \Delta t$$

$$\Delta t = \frac{(t_f - t_o)\ \text{Number of points averaged}}{\text{Total number of points}}$$

There may be some ambient data points recorded on the run tape prior to the start of the test. To conserve computer execution time, these points are overlooked and only the points taken during the test are reduced. The program checks the first three data channels at the start of each run for a 1 F rise in temperature. If a rise is found, the data point following is also checked to confirm that the rise is not a system "blip". After the data point is confirmed, the start time (t_i) is recorded. If no rise in temperature is found in the three data channels, t_i will be taken as the first point encountered in the data set.

The temperatures read-in from the scaled data tape are from thermocouples attached to the outside walls of the heat transfer test section. The individual outside wall temperatures are averaged in groups of n points (n specified by the input data A_{11}). TEMP2 (T_{W2}) is the arithmatic mean of two consecutive averaged groups.

The number of data points to be evaluated can be reduced by assigning a value greater than 1.0 to the sample reduction factor (A_{21}). This would cause the program to skip m-1 groups of data points.

The calculated gas-side wall temperatures corresponding to measured outside-wall temperatures are obtained from the solution of two simultaneous equations:

$$T_{W1} = T_{W2} + \frac{(q/A)\ \zeta}{2k}$$

where k is the thermal conductivity of the wall material, described by a linear function of the mean wall temperature.

$$k = C_1 + C_2 \frac{(T_{W1} + T_{W2})}{2}$$

The solution of the combined expression takes the form:

$$T_{W1} = \frac{-2C_1 + \sqrt{4C_1^2 + 4C_2(C_2T_2^2 + 2C_1T_2 + q/A\ \zeta}}{2C_2}$$

where

$$C_1 = A_1$$

$$C_2 = A_2 \qquad \text{(Read-in values)}$$

$$\zeta = A_{13}$$

The gas temperature may be read-in as a constant, or assigned a thermocouple that measured T_{gas}.

The calculation of the heat flux was based on the following differential heat balance for a relatively thin, highly conductive wall, subject to a heat flux on the front face and insulated on the back face:

$$(q/A)_{N,t} = \rho C_p \zeta \left(\frac{dT_{W2}}{dt}\right)_{N,t}$$

The program is written for test sections with constant wall thickness (ζ) and so the product $\rho\zeta$ is replaced by a constant weight per unit area (W/A). Also, because there are a finite number of data points, the differential dT_{W2}/dt becomes $\Delta T_{W2}/\Delta t$ and the heat flux expression is reduced to:

$$(q/A)_{N,t} = \frac{W}{A} C_p \left(\frac{\Delta T_{W2}}{\Delta t}\right)_{N,t}$$

where specific heat of the wall material is defined as a linear function:

$$C_p = C_1 + C_2 \left(\frac{T_1 + T_2}{2}\right)_{N,t}$$

where

$C_1 = A_{14}$ (Read-in values)

$C_2 = A_{15}$

Finally, the local instantaneous values of the heat transfer coefficients ($h_{N,t}$) for the transfer of heat from the hot nitrogen gas to the test section wall are computed from the following Newtonian convection equation which includes a correction for the bulk temperature drop of the hot nitrogen gas as it flows through the test section and loses heat to the wall:

$$h_{N,t} = \frac{(q/A)_{N,t}}{\left[T_{gi}(t) - \sum_{N=1}^{N} \frac{(q/A)_{N,t} A}{\dot{m}\, C_{pg}} \right] - (T_{W1})_{N,t}}$$

where the specific heat of the gas is:

$$C_{pg} = B_1 + B_2 T_3 + B_3 T_3^{\,2} + B_4 T_3^{\,3}$$

B_1, B_2, B_3, and B_4 are read-in values

There is an option to neglect heat loss if desired, and the expression reduces to:

$$h_{N,t} = \frac{(q/A)_{N,t}}{T_{gi}(t) - (T_{W1})_{N,t}}$$

DATA REDUCTION

Data reduction continued for the model heat transfer experiments. All data from the Brown and Datarite recorders were reduced and tabulated. Gas temperature data were extracted from the Brush recordings of the thermocouple outputs (on-line analog charts of the digitized data). This enabled calculation of the average mass flowrates for the individual tests. All necessary input data were prepared for the machine computations which utilize thermocouple output data in the generation of heat transfer data. Some delay has been enountered with the general usage Beckman transient data unpacking program, TRANS. This hampered data reduction during the major portion of the quarter. The elimination of the problem near the end of the period allowed a full-scale checkout of the entire data reduction system with actual test data, but did not allow ample time for the generation of heat transfer information from the test data. The bulk of the test data reduction will be accomplished near the beginning of the next quarter.

The impingement points and the ignition delays for the individual demonstration motor firings were calculated.

The ignition delay was based on the published master ignition curve for UTP 3001 propellant (Ref. 2). The test section pressure was estimated from Ref. 1 and the unpublished results of this program. The peak heat flux was based on data from the critical experiment.

ANALYTICAL STUDIES

The head-end and aft-end fluid dynamic studies are continuing. Literature is being reviewed to gain additional insight into the fluid dynamic/heat transfer phenomena occuring in these two ignition situations. For example, selected reports gathered for the following general areas include: closely related programs (Ref. 5 through 13); flow over rearward facing steps with and without heat transfer (Ref. 14 through 16); analysis of free and confined jets (Ref. 17); flow in entry regions of tubes (Ref. 18); separated flow in rectangular cavities (Ref. 19); flow in noncircular cross sections with and without heat transfer (Ref. 20); and approximations and techniques utilized in boundary layer calculations (Ref. 21 through 23).

A literature search in support of these studies was completed. The search was restricted to existing material available in the libraries of all North American Aviation divisions. Pertinent books and reports that had not been previously gathered have been requested and will be received at the beginning of the next quarter. The search indicated that a large quantity of related information is available in the open literature. Whether this information is directly applicable to the subject study will be evaluated during the next quarter when a consistent analysis will be formulated and correlations will be established.

FUTURE EFFORT

The testing program is currently 1 month ahead of schedule. Major effort during the fourth quarter will be directed toward data analysis and correlation of the model heat transfer experiments. Demonstration motor firings will be conducted near the middle of the period.

NOMENCLATURE

C_p = specific heat of the wall material (Btu/lb-F)

C_{pg} = specific heat of the gas at constant pressure (Btu/lb-F)

h = heat transfer coefficient (Btu/in.^{2}-sec-F)

$\dot{m}$ = gas flowrate (lb/sec)

q/A = heat flux (Btu/in.^{2}-sec)

t = time (seconds)

T_{gi} = gas temperature (F)

T_{W1} = test section inside wall temperature (F)

T_{W2} = test section outside wall temperature (F)

W/A = weight per unit surface area (lb/in.^{2})

ρ = density (lb/in.^{3})

ζ = test section wall thickness (inches)

k = thermal conductivity of the wall material (Btu/in.-sec-F)

Subscripts

g = gas

i = initial

N = axial station number

t = time

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13. ABSTRACT

This program is concerned with determining the convective heat transfer characteristics of pyrogen igniters in both the aft-end and head-end configurations for three-pointed star and conocyl motor grains. Heat transfer modeling tests using thin-plate calorimetric techniques are being used to evaluate the heat transfer distributions. The third quarter effort reported herein was directed toward completion of the model heat transfer tests, preparation of the model heat transfer data for machine computation, initiation of build-up for the demonstration motor firings, continuance of the head-end and aft-end fluid dynamic analysis, completion of a description of the "HOTGAS" computer program, and initiation of that portion of data reduction requiring machine computation.

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14. KEY WORDS	LINK A ROLE	LINK A WT	LINK B ROLE	LINK B WT	LINK C ROLE	LINK C WT
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